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# RESEARCH MEMORANDUM

for the

Air Research and Development Command, U. S. Air Force

PERFORMANCE OF 15-STAGE EXPERIMENTAL J71

AXIAL-FLOW COMPRESSOR

III - EFFECTS OF INLET-GUIDE-VANE ADJUSTMENT

By James G. Lucas and Richard E. Filippi

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RESEARCH MEMORANDUM

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Air Research and Development Command, U. S. Air Force

## PERFORMANCE OF 15-STAGE EXPERIMENTAL J71 AXIAL-FLOW COMPRESSOR

## III - EFFECTS OF INLET-GUIDE-VANE ADJUSTMENT

By James G. Lucas and Richard E. Filippi

## SUMMARY

The over-all and individual stage performance characteristics were determined for the 15-stage experimental J71 axial-flow compressor at two different settings of the adjustable inlet guide vanes. As was expected, closing the guide vanes  $6^\circ$  caused the maximum weight flow and stall pressure ratio at design speed to be noticeably decreased. Over the low-speed range, the stall-limit line was moved to somewhat higher pressure ratios for a given equivalent weight flow by the guide-vane resetting. At the increased guide-vane setting angle, the first-stage equivalent-pressure-ratio curve was shifted to lower values of both flow coefficient and pressure ratio. The second-stage curve suffered a slight decrease in equivalent pressure ratio at the higher speeds, but no effect could be noticed on later stages.

## INTRODUCTION

The over-all performance of the experimental 15-stage J71 axial-flow compressor, with fixed inlet guide vanes, was very poor over the entire speed range, as reported in reference 1. The individual stage performance characteristics for the test compressor, reported in reference 2, indicated that the inlet stage was contributing heavily to the poor over-all performance. Because the effects of inlet-guide-vane adjustments are noticed almost solely on the performance of the inlet stage of a compressor (ref. 3), it was felt that some improvement could be made on the present compressor by such an adjustment. Therefore, the compressor was tested at the NACA Lewis laboratory to determine the effects on its over-all and individual stage performance characteristics of changes in the inlet-guide-vane setting angles. The test compressor, which was originally fitted with fixed inlet guide vanes, was refitted with an externally adjustable set of vanes for this investigation.

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It was expected that, during the course of the program, the compressor over-all and individual stage performance characteristics would be determined over a wide range of speeds and air flows at several guide-vane settings over the available range. However, because of failure of the test compressor, data were obtained at only two different settings, along with a single point at a third setting.

In addition, a simple flow analysis was made on the basis of the test results to determine the inlet flow conditions to the first rotor row at the guide-vane positions investigated.

### APPARATUS, INSTRUMENTATION, AND PROCEDURE

The apparatus and over-all performance instrumentation for the present tests are the same as outlined in reference 1, except that the compressor was not insulated. The interstage instrumentation is the same as that described in reference 2. Test operation and data presentation procedures are also as outlined in reference 2.

The externally adjustable inlet-guide-vane assembly used during these tests had an adjustment range of  $46^\circ$  divided equally about a position at which the tip-section setting angle was the same as that for the original fixed vanes.

During the latter part of the program, an angle-measuring probe was installed immediately after the inlet-guide-vane assembly in a radially traversing probe actuator. The instrument was located circumferentially in such a position that it would not be in the wake of an upstream strut or guide vane.

### RESULTS AND DISCUSSION

In the following discussion the midpoint of the adjustment range, where the tip-section setting angle duplicates that of the original fixed vanes, is termed the  $0^\circ$  setting. Deviations from this setting are labeled plus or minus to indicate, respectively, greater or less guide-vane incidence angle and therefore turning angle.

#### Over-All Performance

Comparison of  $0^\circ$  and fixed-vane compressors. - The over-all performance characteristics for the compressors with fixed guide vanes and with the  $0^\circ$  setting are compared in figure 1. Curves of over-all total-pressure ratio and adiabatic temperature-rise efficiency are plotted against equivalent weight flow at several constant speeds from 30 to 100

percent of design. The performance curves obtained with the fixed-guide-vane compressor are reproduced from reference 2. At 80- and 100-percent speed, the data taken at the  $0^\circ$  setting were insufficient to obtain well-defined curves. No satisfactory comparisons of performance can be made in the intermediate-speed range (70 to 80 percent of design) because of the multiplicity of characteristic curves that can be obtained at a given speed in this range for this compressor (ref. 4). At design speed the maximum flow of the  $0^\circ$  compressor is about 5 pounds per second higher than that of the fixed-vane compressor. This indicates that the adjustable inlet guide vanes are turning the air less at the  $0^\circ$  setting than were the fixed vanes. At the lower speeds, between about 50 and 75 percent of design, the stall-limit line was adversely affected at the  $0^\circ$  setting as compared with the fixed-vane version.

Comparison of  $0^\circ$  and  $+6^\circ$  compressors. - The over-all performance characteristics for the compressor at the guide-vane settings of  $0^\circ$  and  $+6^\circ$  are compared in figure 2. The figure indicates that closing the vanes  $6^\circ$  resulted in a drop of 6.5 pounds per second in maximum flow. The stall-limit line was improved somewhat in the low-speed region by resetting the guide vanes.

No difference was observed in the number of stall zones in the rotating-stall patterns between the two compressor configurations. Over the low- and intermediate-speed ranges, four stall zones existed at most of the data points.

Performance at  $-5^\circ$  guide-vane setting. - At the guide-vane setting of  $-5^\circ$ , only a maximum flow point at design speed was obtained. The flow recorded was 168.5 pounds per second. However, after the compressor was surged at this speed and the throttles were reopened for maximum flow, the weight flow had dropped to about 151 pounds per second. Inspection revealed that the exceptionally violent surge had caused the inlet guide vanes to twist to a more closed position. The pilot vanes and the external linkage had been permanently distorted, and the rest of the vanes had closed about  $15^\circ$  to  $20^\circ$ . As a result, the guide-vane assembly had to be replaced, and the external adjustment linkage was strengthened considerably. No further data were obtained at this guide-vane setting.

#### Flow Conditions After Inlet Guide Vanes

Conditions during unstalled flow. - A curve of measured guide-vane-exit flow angle at the  $+6^\circ$  setting is presented in figure 3 as an average of the data points obtained at the higher speeds during unstalled flow. The angle measurements are presented as plots of guide-vane-exit angle measured from the axial direction against percentage of passage height from the hub. From this curve the corresponding curve was derived for the  $0^\circ$  setting considering the effects to be expected from the change in

incidence and deviation angles. This curve is also presented in figure 3, along with the original design distribution. At the  $0^\circ$  setting, the turning is lower than that predicted by the design over the entire span, except at the hub radius.

The low turning at the  $0^\circ$  setting has the effect, compounded by the lower-than-design flow at design speed, of increasing the first-rotor incidence angles and decreasing the relative Mach numbers on the first rotor as shown in figure 4. These curves were obtained by using simple radial equilibrium and the stall-point weight flow obtained at design speed with each vane setting. The increased incidence level would be raised even more at speeds below design, which would result in the poor off-design performance that has previously been shown to exist. The tip incidence angle is almost unaffected by the guide-vane resetting from  $0^\circ$  to  $+6^\circ$  (fig. 4), while the effect increases rapidly toward the hub. This trend was previously noted in reference 3.

Conditions during stalled flow. - The angle measurements taken after the guide vanes at the stall points at speeds of 50, 65, and 75 percent of design with the  $+6^\circ$  guide-vane setting are presented in figure 5. The very high air angles over the outer half of the passage result from low axial velocities in this region and indicate that the tip section of the rotor blade is stalled. The flow in the tip region was sufficiently poor that no consistent angle measurements could be made. It can be seen that the tip stall does not penetrate as deep radially at 75-percent speed as at the lower speeds; and at higher speeds the tip stall disappears completely, as indicated by the measured angles in figure 3.

#### Individual Stage Performance

The first- and second-stage performance characteristics for the compressor with  $0^\circ$  and  $+6^\circ$  guide-vane settings are shown in figures 6 and 7, respectively. These characteristics are plotted as equivalent total-pressure ratio against the flow coefficient at the stage inlet.

First-stage performance at two guide-vane settings. - Figures 6(a) and 7(a) are replotted in figure 8 as faired curves of first-stage performance for the purpose of comparison. This figure indicates that, with a  $+6^\circ$  resetting of the inlet guide vanes, the entire curve is moved to lower values of flow coefficient over the entire range and to lower values of equivalent pressure ratio over most of the range. The lower flow coefficients are direct reflections of the lower over-all flows at the various speeds tested, while the lower pressure ratios are caused by the decreased first-rotor relative Mach number level as shown in figure 4. This shift in the first-stage characteristic curve is in agreement with the results of reference 3.

At design speed, the first-stage data points should cover only a small range of equivalent pressure ratio, with the stall point at the highest value. Since the data indicate a pressure drop at two points, including the stall point, the pressure measurements after the first stage were evidently low at these two points.

Second-stage performance at two guide-vane settings. - Figures 6(b) and 7(b) are replotted in figure 9 as faired curves of second-stage performance. This figure indicates that resetting the guide vanes to  $+6^\circ$  has a very small effect on the second-stage performance. Some change in equivalent pressure ratio is noted at the high speeds, although the  $+6^\circ$  curve does not drop off as would be expected, probably because of low measured pressures after the first stage. These low pressures also explain the high flow coefficients at the high-speed end of the curve.

Performance of later stages. - The performance curves for stages 3 to 15 are not presented, since no effects of guide-vane resetting could be recognized and both sets of data are essentially the same as the set presented in reference 2.

#### SUMMARY OF RESULTS

The following results were obtained from an investigation of the 15-stage experimental J71 axial-flow compressor using adjustable inlet guide vanes:

1. The surge line over the low-speed range was improved by increasing the guide-vane turning by  $6^\circ$ .
2. With the guide vanes reset  $6^\circ$  for more turning, the maximum weight flow and maximum pressure ratio were reduced at design speed.
3. The increased guide-vane turning caused the first-stage characteristic curve to be shifted to lower values of flow coefficient and the peak equivalent pressure ratio to be reduced. The second-stage pressure ratio was decreased somewhat at high speeds by the change, but no effect could be noticed on later stages.

Lewis Flight Propulsion Laboratory  
National Advisory Committee for Aeronautics  
Cleveland, Ohio, April 11, 1955

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3. Budinger, Ray E., and Kaufman, Harold R.: Investigation of the Performance of a Turbojet Engine with Variable-Position Compressor Inlet Guide Vanes. NACA RM E54L23a, 1954.
4. Lucas, James G., and Filippi, Richard E.: Multiple Over-All Performance and Rotating-Stall Characteristics of a 15-Stage Experimental Axial-Flow Compressor at an Intermediate Speed. NACA RM E54C29, 1954.

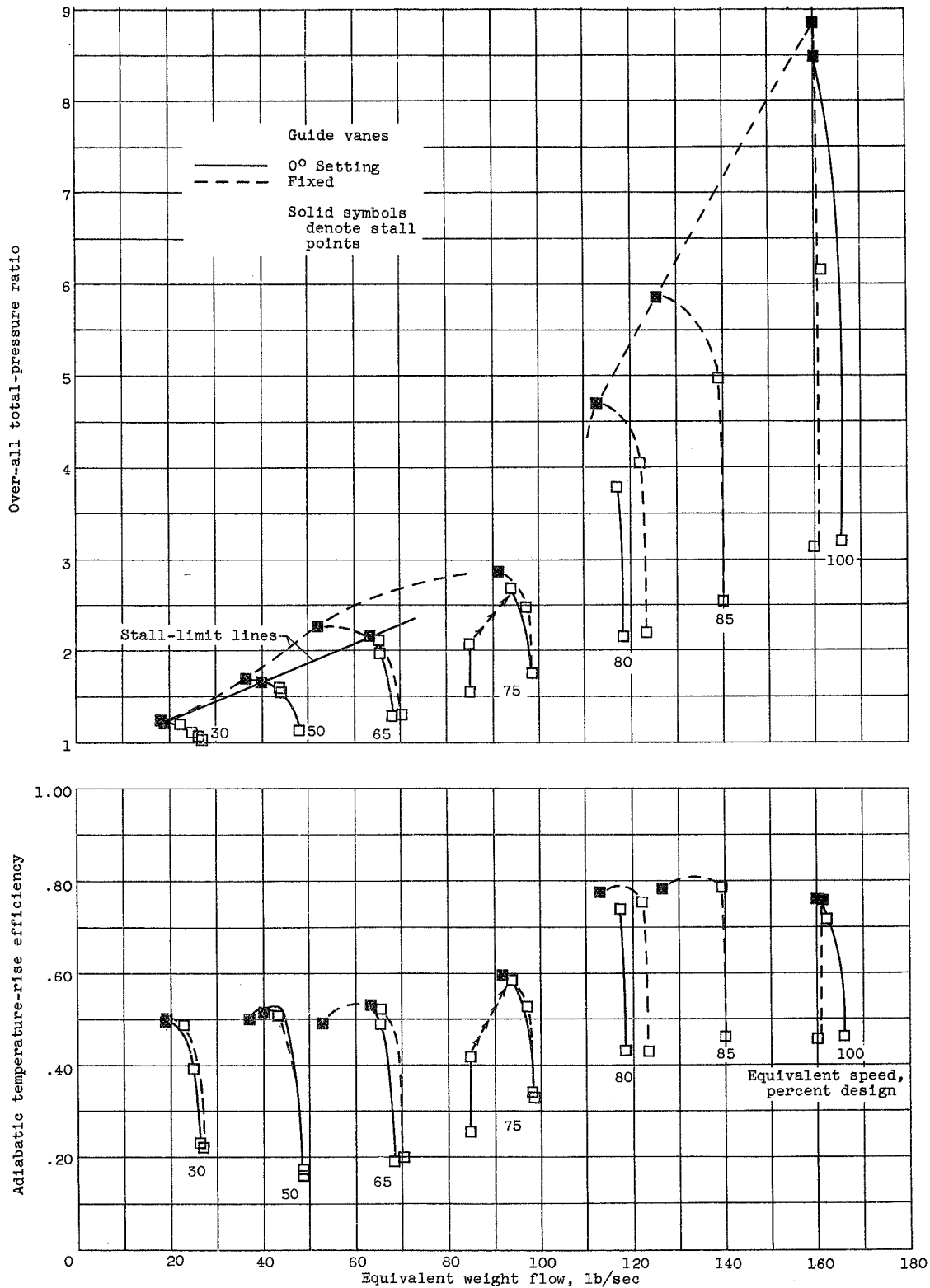


Figure 1. - Comparison of over-all performance of compressors with fixed inlet guide vanes and with adjustable vanes set at 0°.



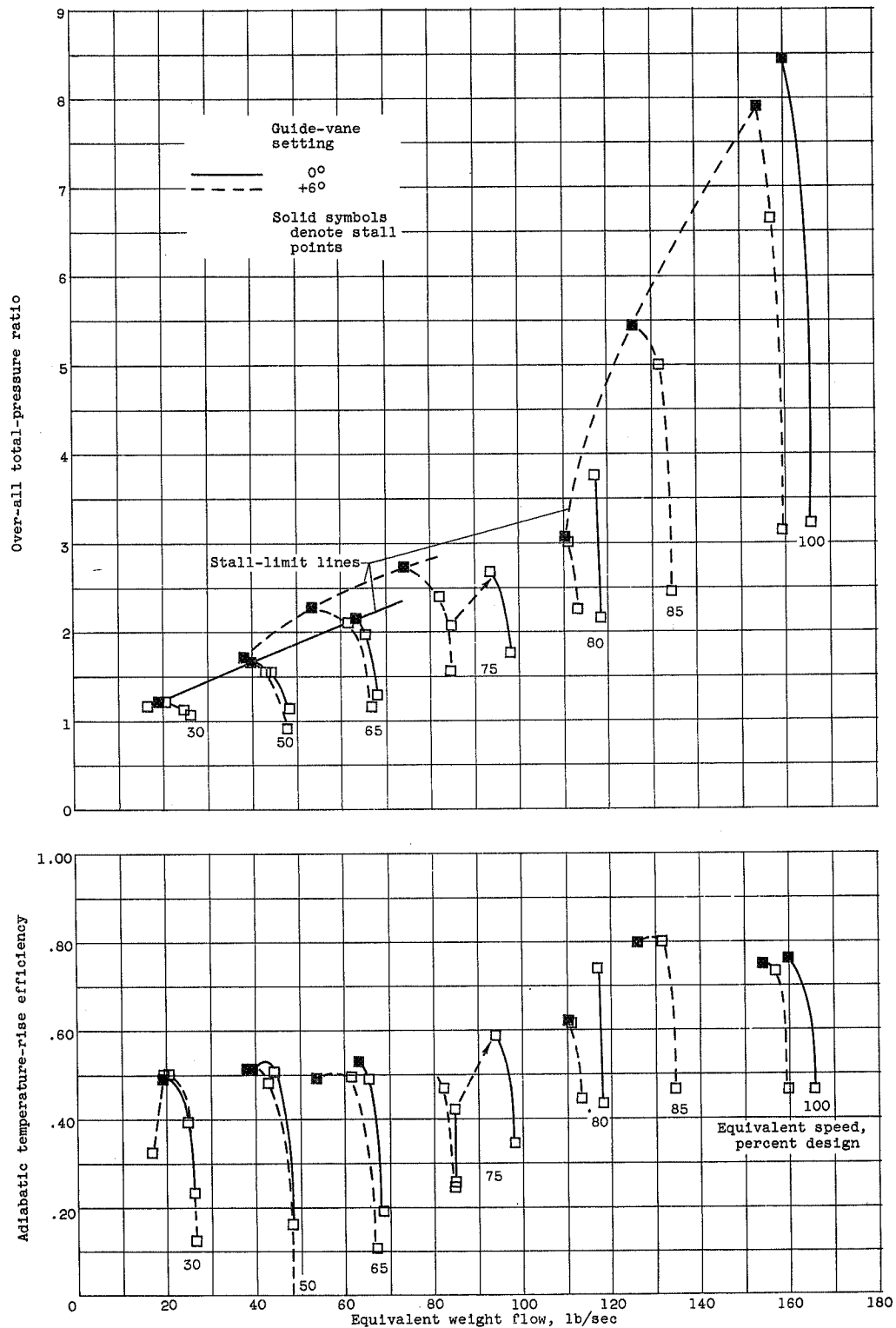


Figure 2. - Comparison of over-all performance of compressors with 0° and +6° inlet-guide-vane settings.

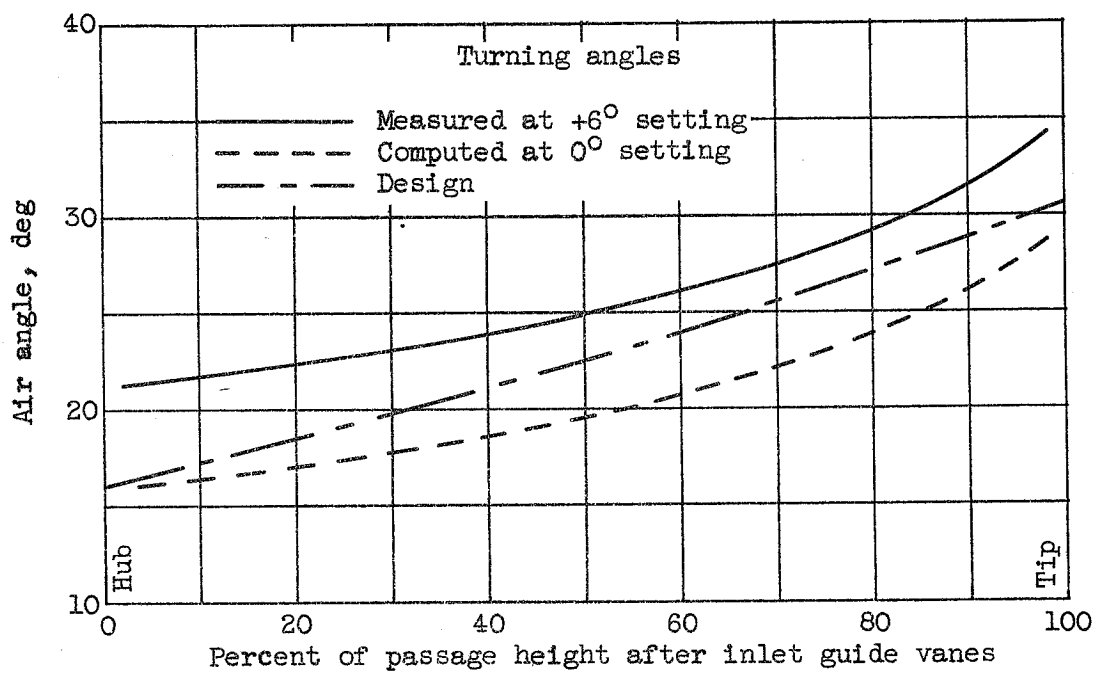


Figure 3. - Comparison of inlet-guide-vane turning angles.

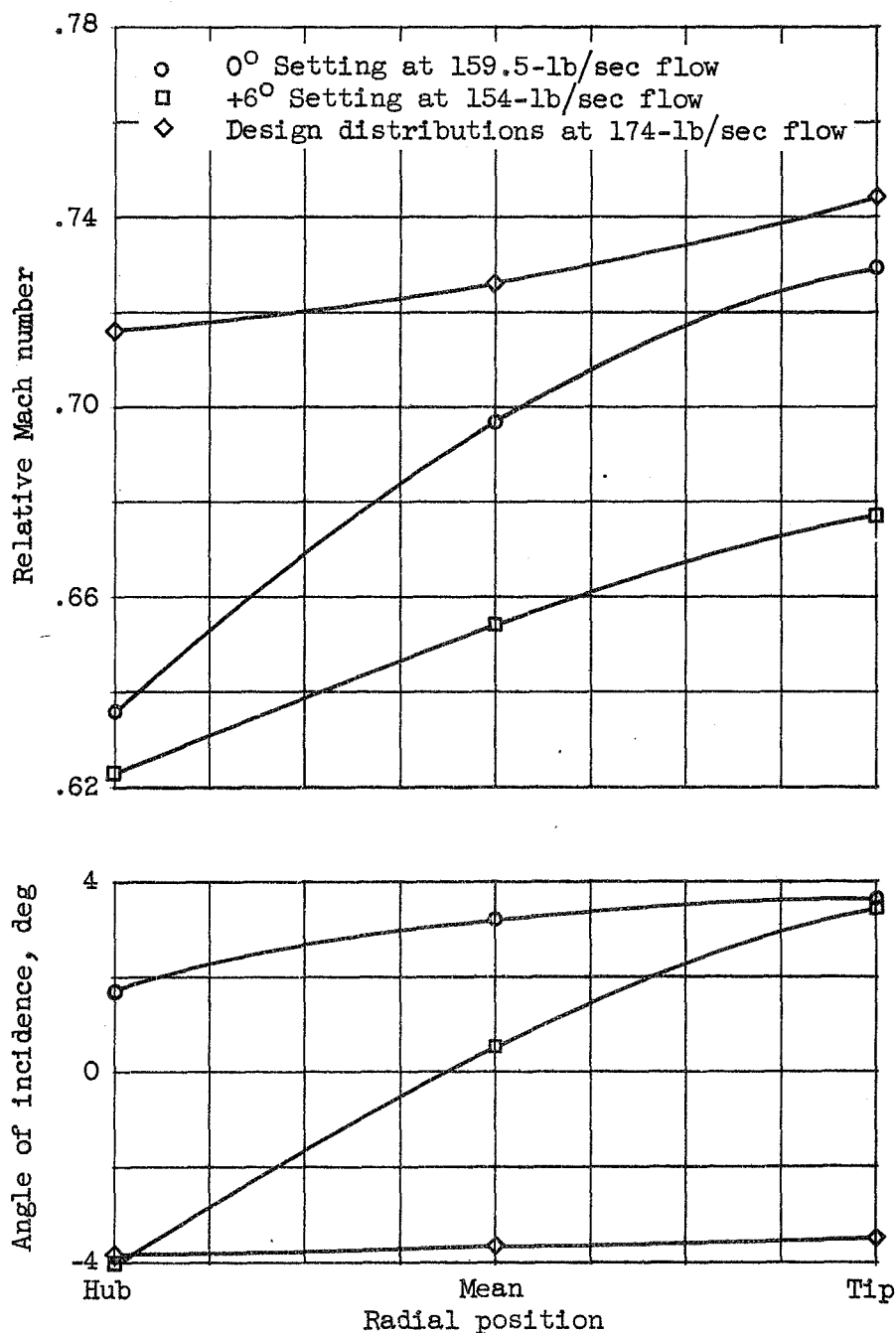


Figure 4. - Radial distributions at design speed of first-rotor incidence angles and relative Mach numbers for two inlet-guide-vane settings compared with design distributions.

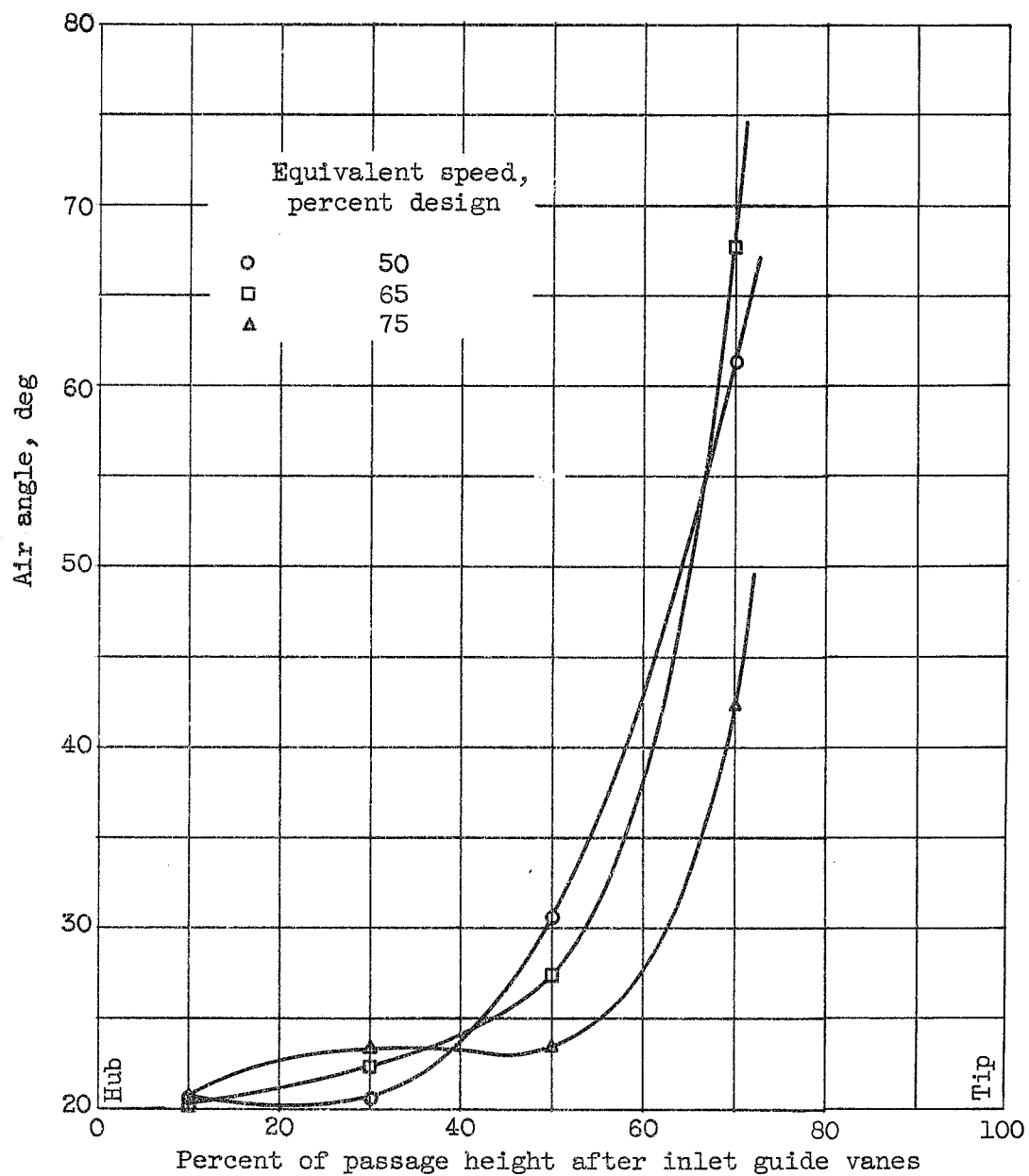


Figure 5. - Air angles measured after inlet guide vanes at stall points with  $+6^\circ$  vane setting.

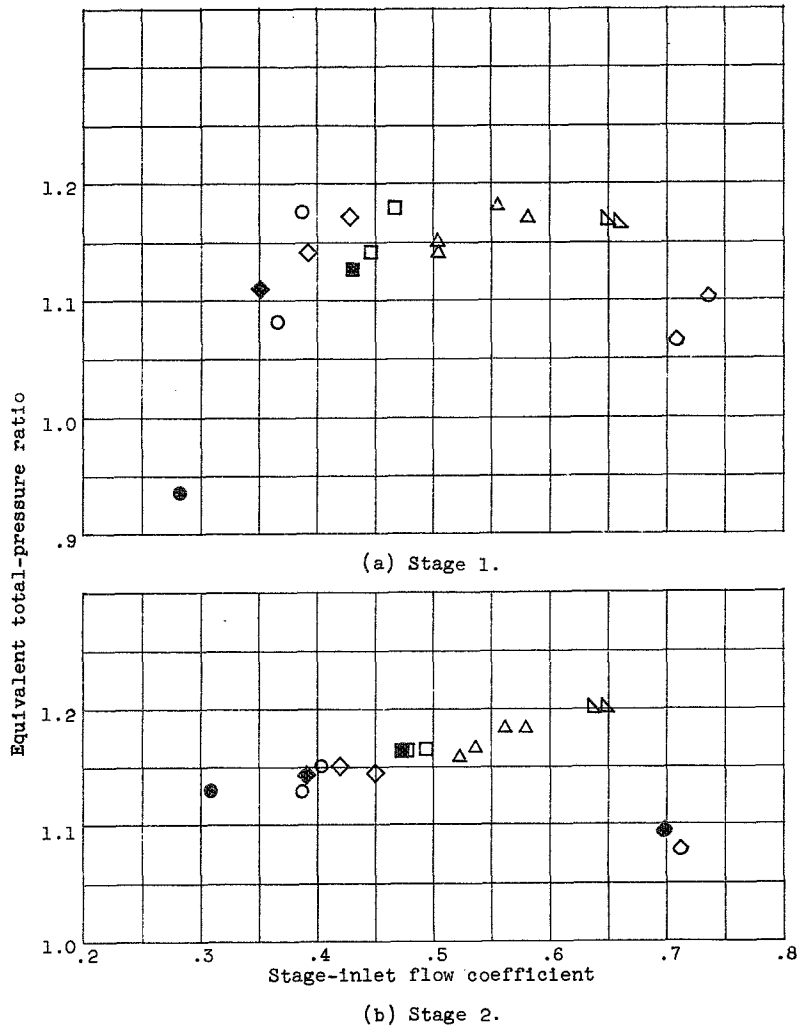


Figure 6. - Individual stage performance characteristics with  $0^\circ$  guide-vane setting.

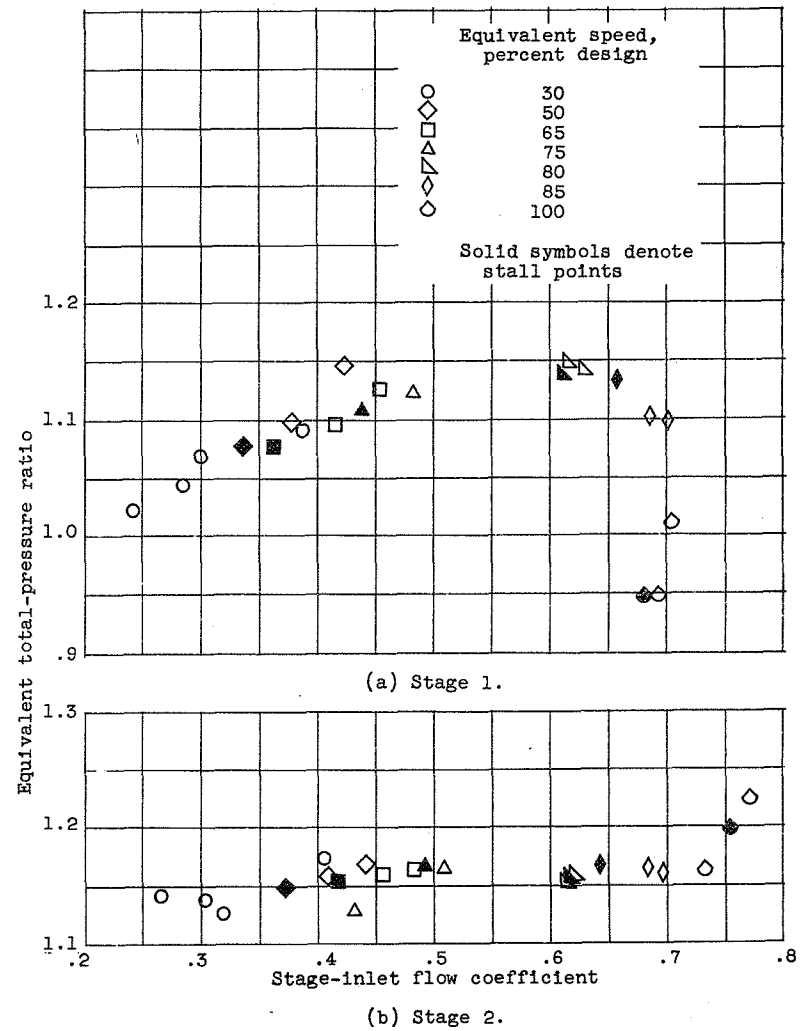


Figure 7. - Individual stage performance characteristics with  $+6^\circ$  guide-vane setting.



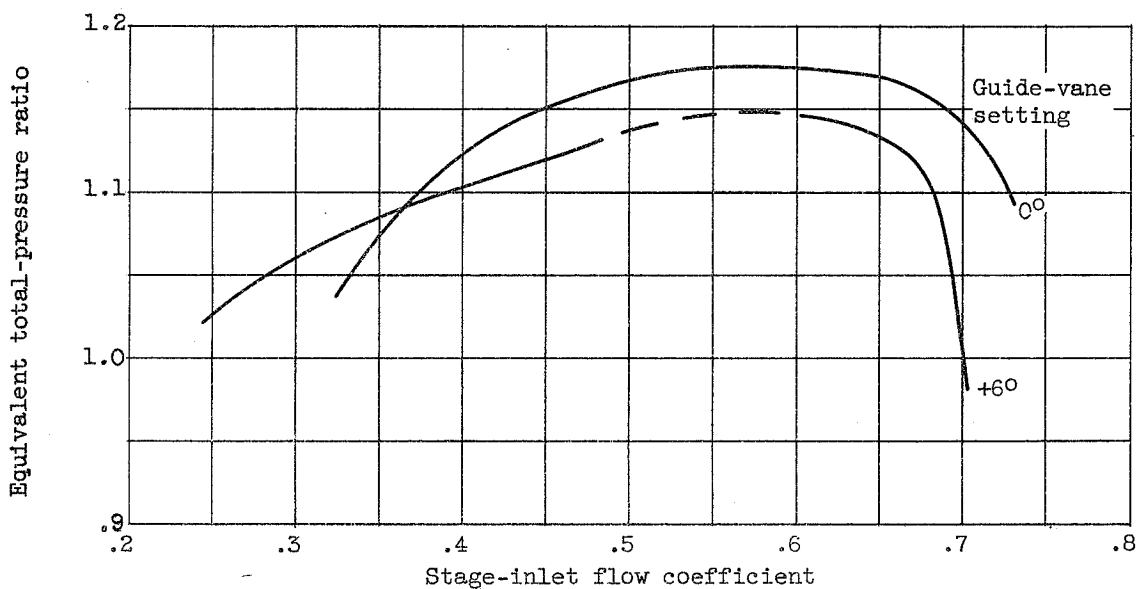


Figure 8. - Comparison of first-stage performance at two guide-vane settings.

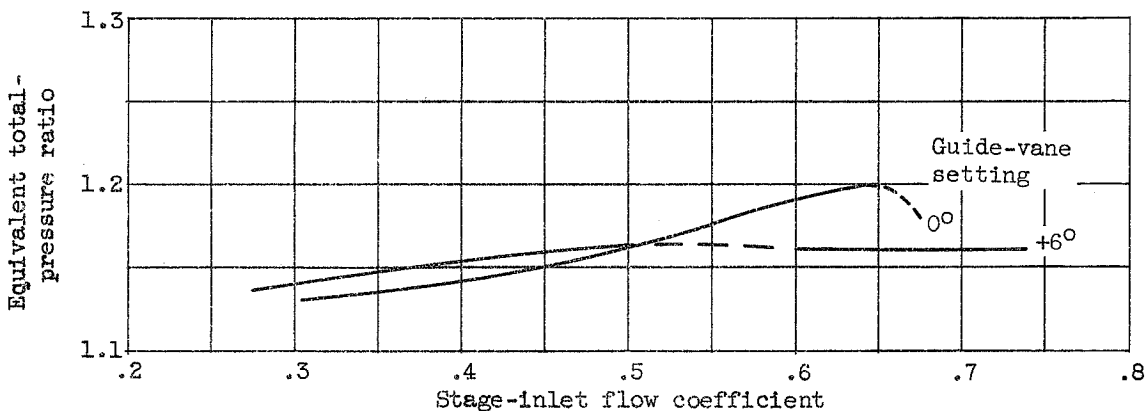
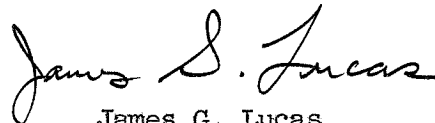


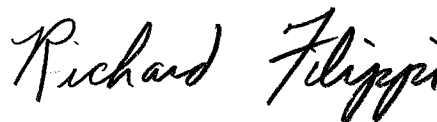
Figure 9. - Comparison of second-stage performance at two guide-vane settings.

PERFORMANCE OF 15-STAGE EXPERIMENTAL J71 AXIAL-FLOW COMPRESSOR

III - EFFECTS OF INLET-GUIDE-VANE ADJUSTMENT



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## PERFORMANCE OF 15-STAGE EXPERIMENTAL J71 AXIAL-FLOW COMPRESSOR

### III - EFFECTS OF INLET-GUIDE-VANE ADJUSTMENTS

#### Abstract

The stall-limit line at low speeds was improved somewhat by closing the inlet guide vanes  $6^\circ$ , while the design-speed maximum flow and pressure ratio were reduced. The first-stage characteristic curve was moved to lower values of both flow coefficient and equivalent pressure ratio. The second-stage pressure ratio was decreased slightly at high speeds, while the later stages were unaffected.